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(56) Documents cited
GB 2184237 A   GB 2184231 A   GB 2159947 A

(58) Field of search
UK CL (Edition J) G1G GER GEV
INT CL⁴ G01H, G01V

(54) **A demodulator circuit for an interferometer type of hydrophone**

(57) The optical signal in a fiber optic interferometer (20) is phase modulated to provide a carrier signal for phase changes caused by changes in a physical parameter such as sound, being sensed. The signal is then demodulated to measure changes in the parameter. A crystal oscillator (52) frequency reference and passive filtering cause the circuit to have low phase noise. Digital phase shifters (96, 98) provide mixer references that have low phase noise and stable gain. The signal processing techniques used are applicable to sensor arrays using a single carrier excitation source, time demultiplexing of individual carrier signals and demodulation of each sensor carrier signal. This demodulator circuit is also applicable to frequency-multiplexed approaches, which utilize direct frequency modulation of the source slightly unbalanced interferometers, and electronic frequency-division multiplexing. The passive homodyne technique allows large linear dynamic range of about 100 dB so that both small and large amplitude signals commonly encountered in acoustic sensing applications may be observed with excellent fidelity.
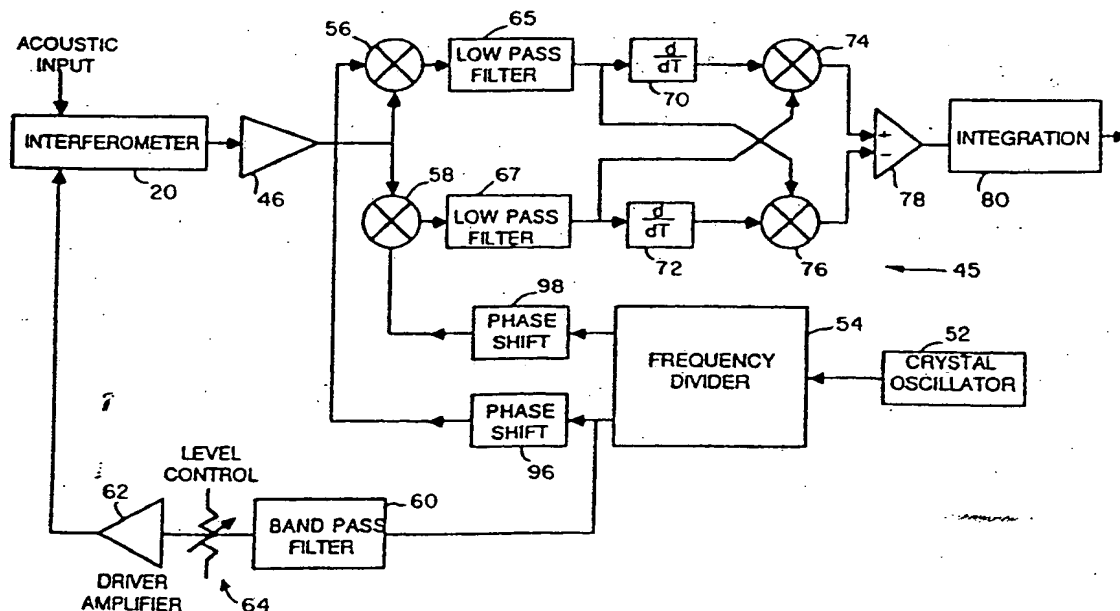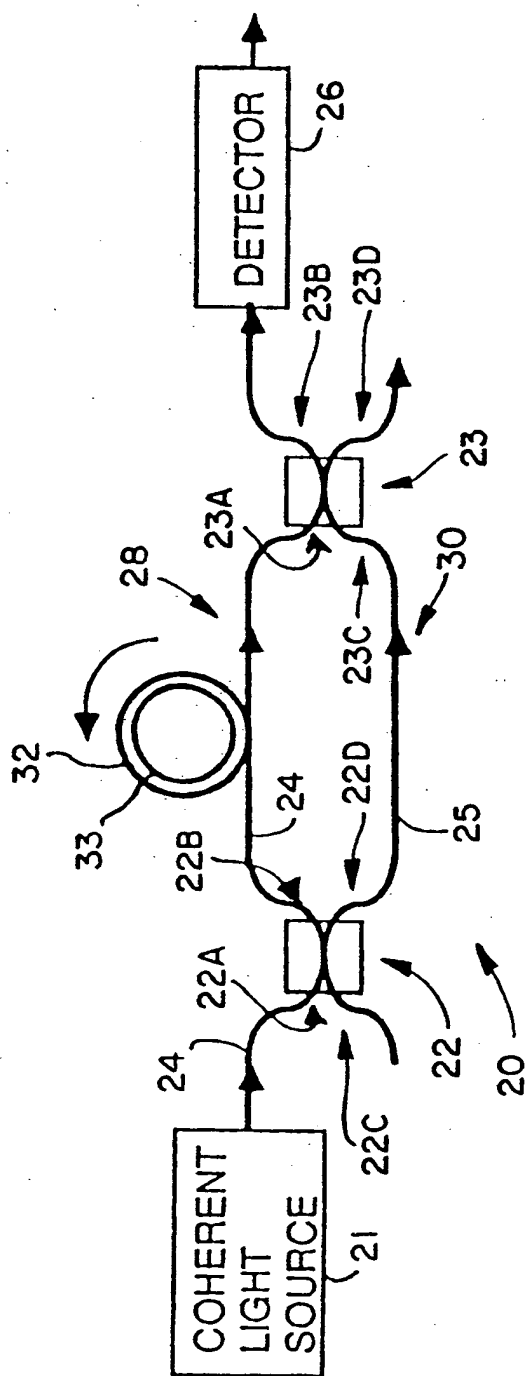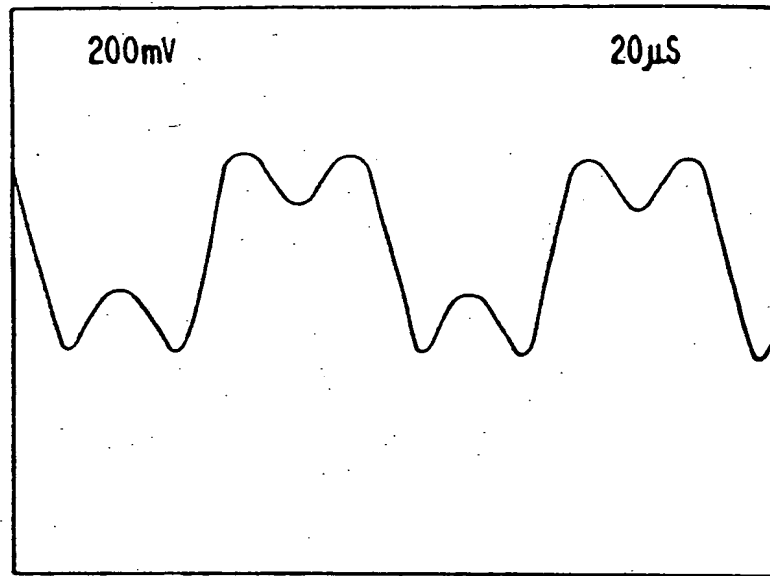
FIG.6

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FIG.1
(PRIOR ART)

COHERENT LIGHT SOURCE 21

DETECTOR 26

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(a) OSCILLOSCOPE TRACE
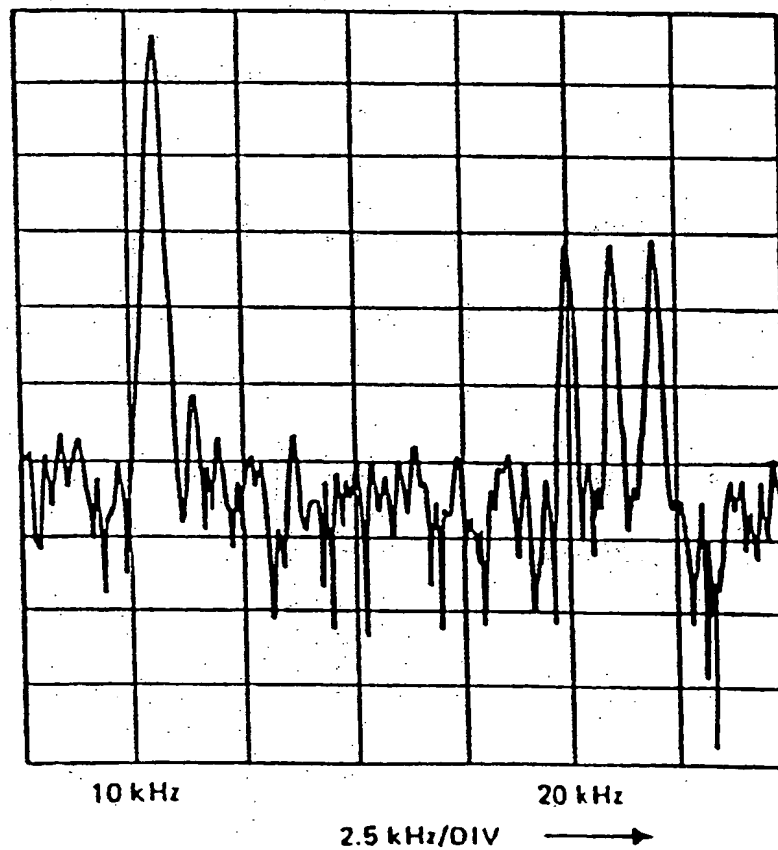

FIG.2   (b) SIGNAL SPECTRUM

200mV   20µS

(a) OSCILLOSCOPE TRACE

0 dBm
REFERENCE
LEVEL

10 dB/DIV

10 kHz   20 kHz
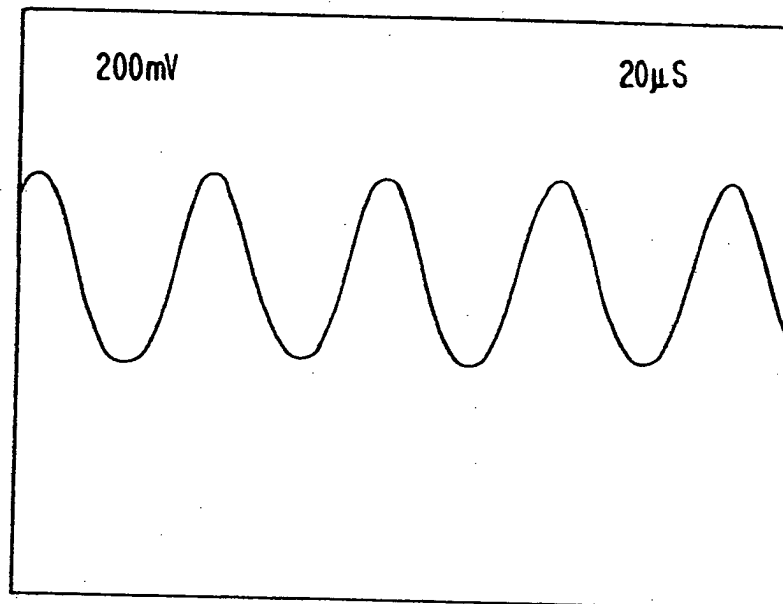
2.5 kHz/DIV ⟶
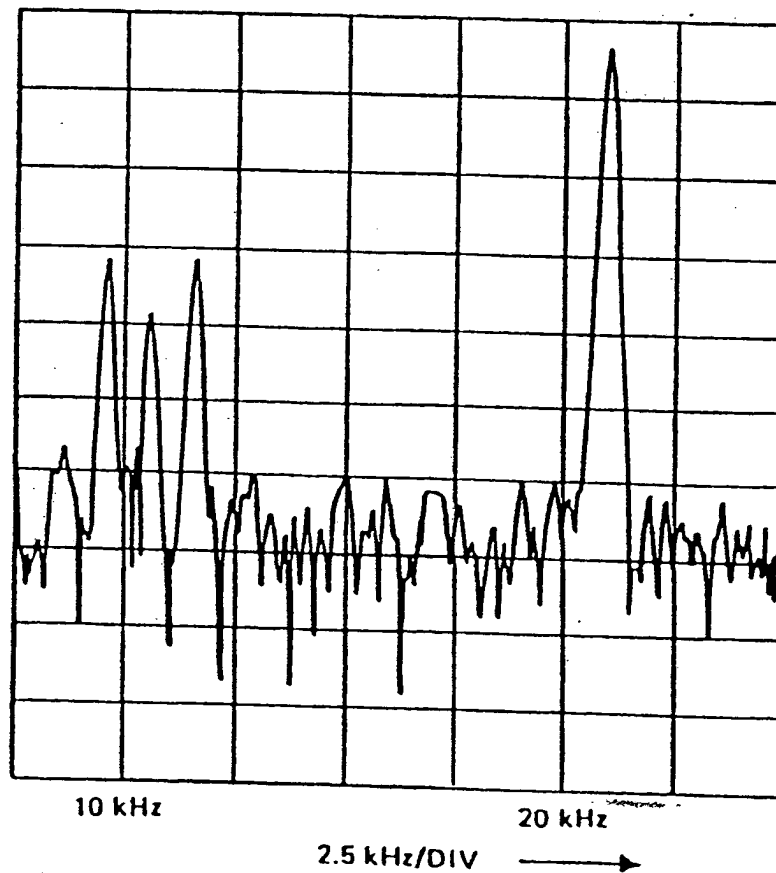
FIG.3   (b) SIGNAL SPECTRUM

200mV   20µS

(a) OSCILLOSCOPE TRACE

0 dBm
REFERENCE
LEVEL

↑

10 dB/DIV

10 kHz   20 kHz

2.5 kHz/DIV ──────▶

FIG.4   (b) SIGNAL SPECTRUM

FIG. 5

FIG.6

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CRYSTAL
OSC. 52

COUNTER 54   10.4 KHy

85

BUFFER

CLOCK   DATA
SHIFT REGISTER
OUTPUTS

CLOCK   DATA
SHIFT REGISTER
OUTPUTS

SELECT
PHASE

SELECT
PHASE

MIXER REFERENCE

MIXER REFERENCE

FIG.7

60

BAND PASS
FILTER

103   105

FIG.8

FIG.9

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FIG.10

FIG.11
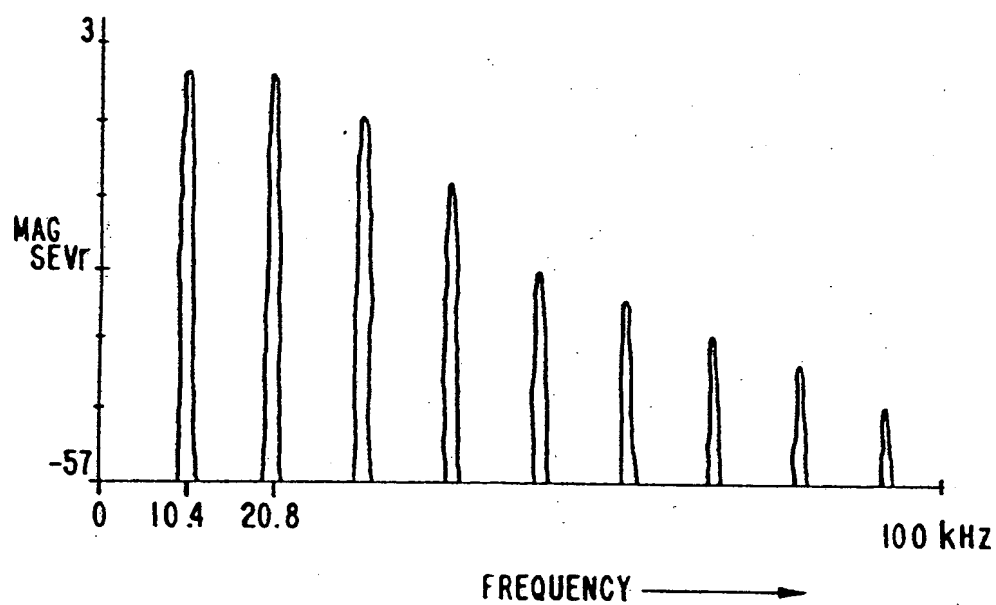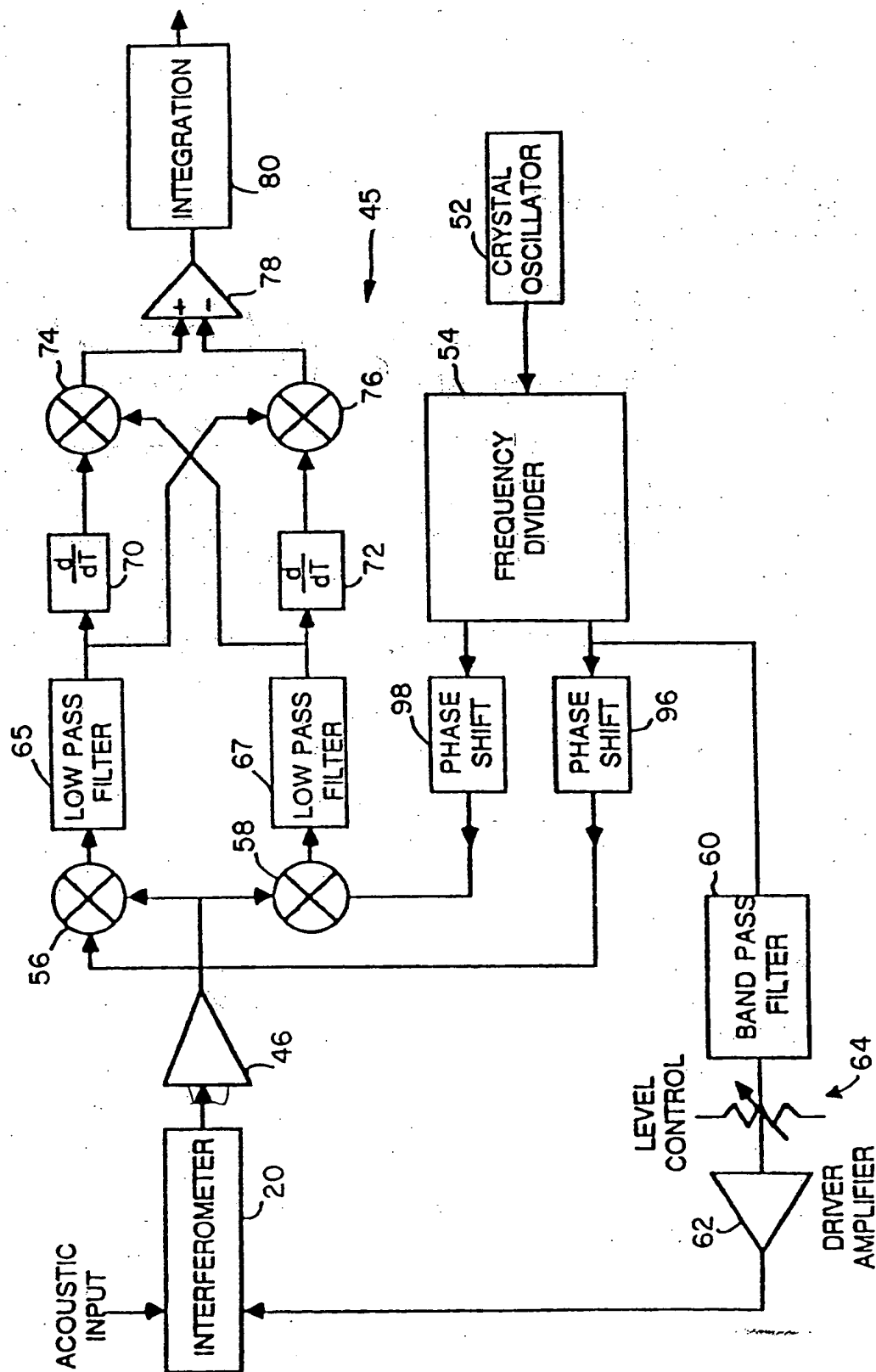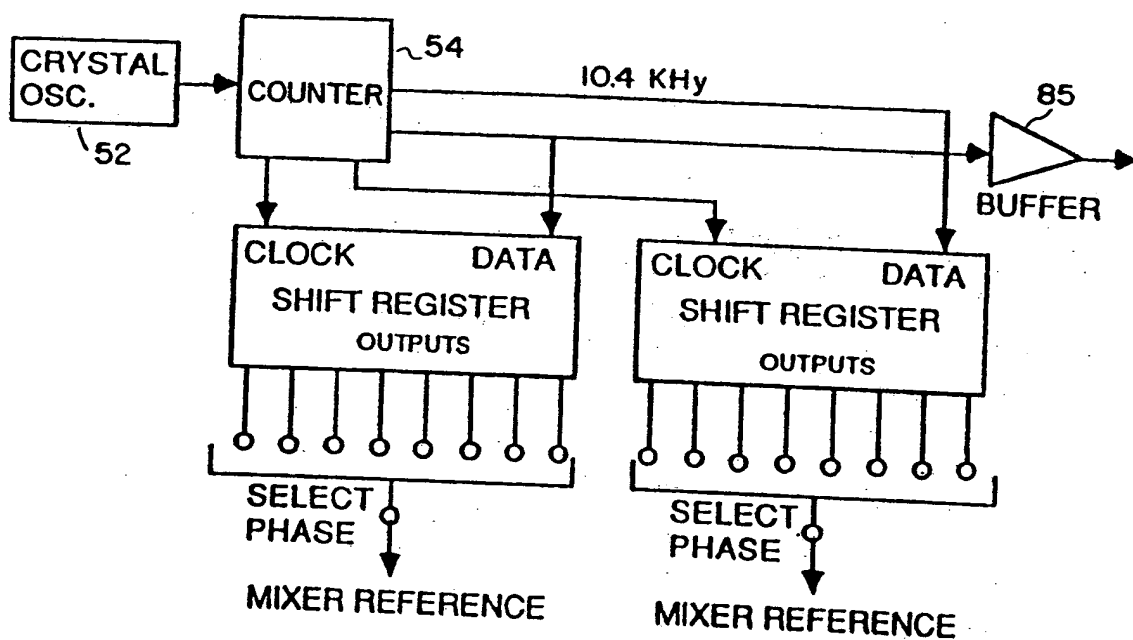
HYDROPHONE DEMODULATOR CIRCUIT AND METHOD

BACKGROUND OF THE INVENTION

This invention relates to fiber optic interferometric sensors that respond to perturbations such as acoustic wavefronts by producing a
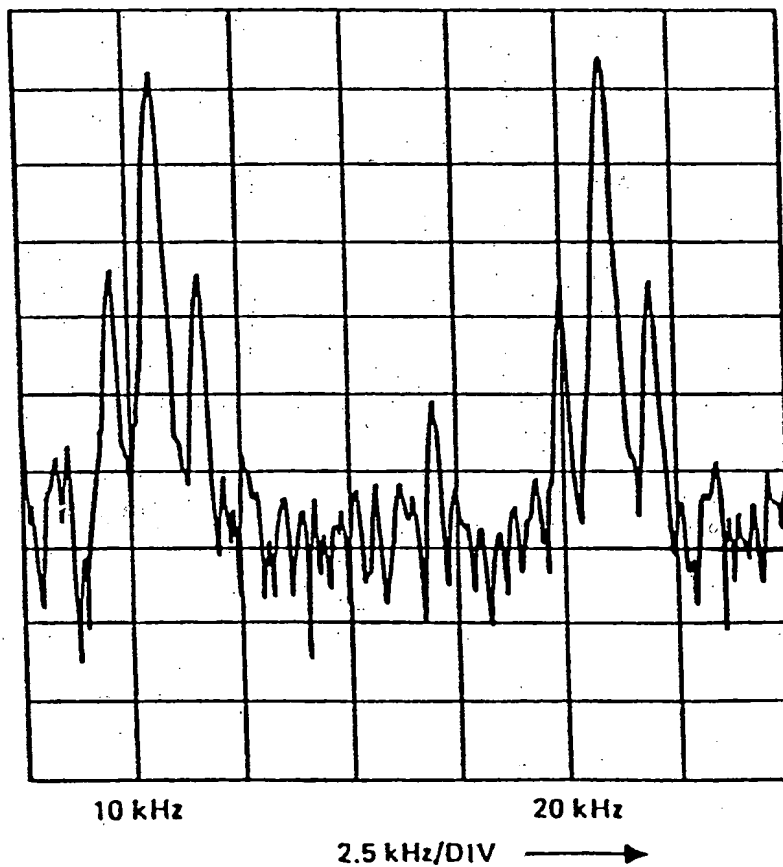
5 phase difference in two light beams propagated by fiber optic material. Still more particularly, this invention relates to recovering the acoustic input signal from the signal developed by the optical fiber interferometer used to sense the acoustic energy.

Optical fibers can be made sensitive to a large number of physical

10 phenomena, such as acoustic waves and temperature fluctuations. An optical fiber exposed to such phenomena changes the amplitude, phase or polarization of light guided by the fiber. Optical fibers have been considered for use as sensing elements in devices such as hydrophones, magnetometers, accelerometers and electric current sensors.

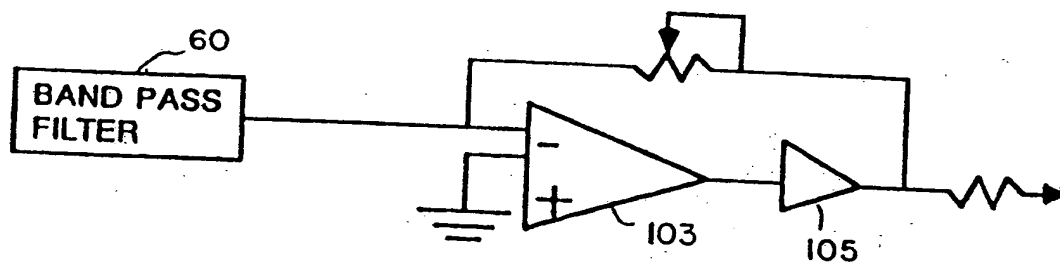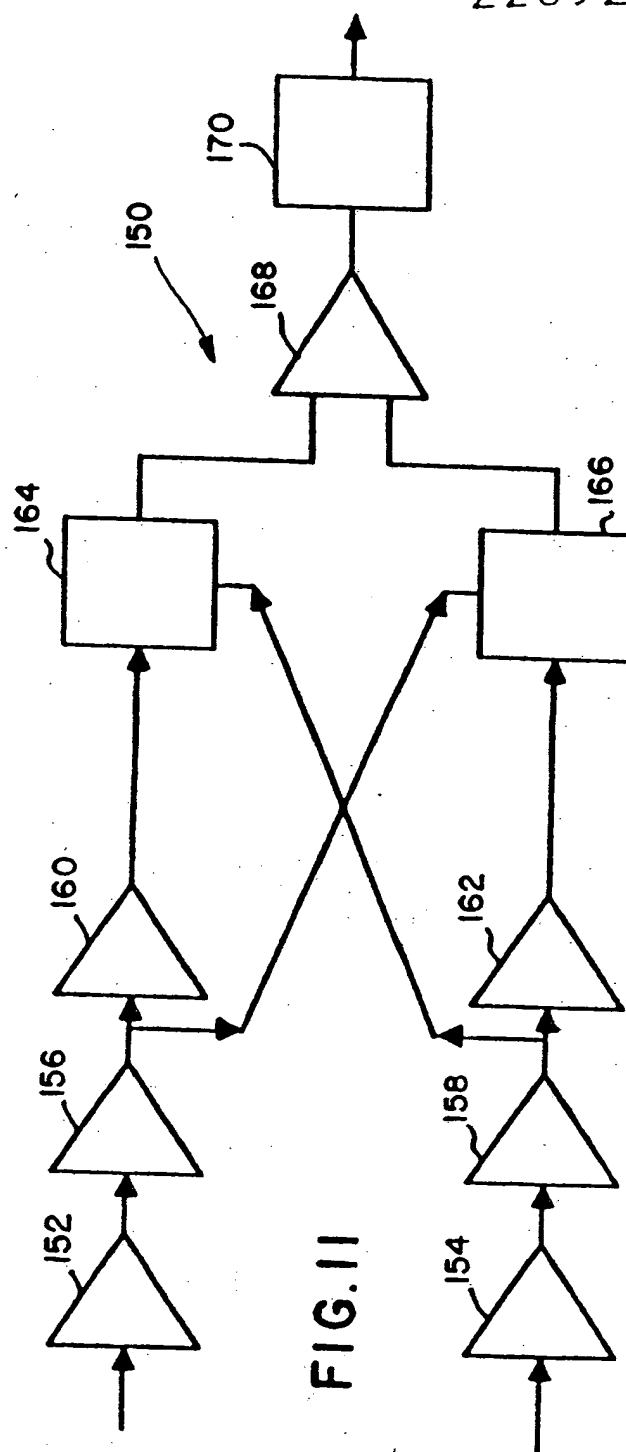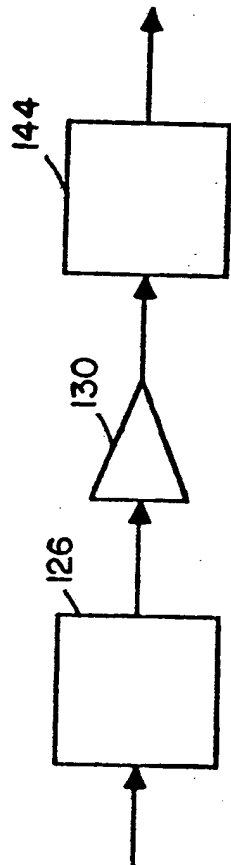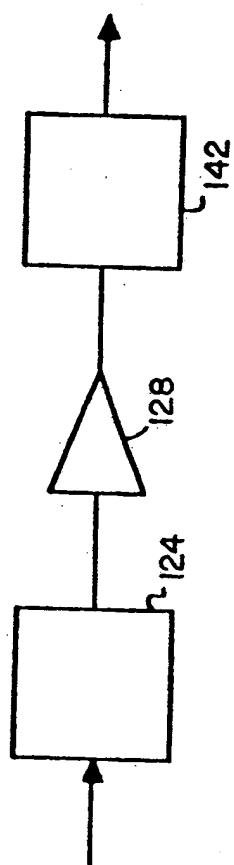15 Mach-Zehnder, Michelson, Sagnac, and resonant ring interferometers have been used as sensors. Mach-Zehnder, Michelson and Sagnac interferometers respond to the phenomenon being sensed by producing phase differences in interfering light waves. Detecting phase changes in the waves permits quantitative measurements to be made on

20 the physical quantity being monitored. The Sagnac interferometer produces phase differences in two counter- propagating light waves in a coil of a single fiber in response to rotations about the axis of the coil.

The Mach-Zehnder interferometer is particularly suited to sensing acoustic vibrations. A fiber optic Mach-Zehnder interferometer typically

25 has a reference arm comprising a first length of optical fiber and a sensing

arm comprising a second length of optical fiber. The sensing arm is exposed to a physical parameter, such as an acoustic wavefront, to be measured while the reference arm is isolated from changes in the parameter. When the Mach-Zehnder interferometer is used as an acoustic

5 sensor, acoustic wavefronts change the optical length of the sensing arm as a function of the acoustic wave amplitude. An optical coupler divides a light signal between the two arms. The signals are recombined after they have propagated through the reference and sensing arms, and the phase difference of the signals is monitored. Since the signals in the reference

10 and sensing arms had a definite phase relation when they were introduced into the arms, changes in the phase difference are indicative of changes in the physical parameter to which the sensing arm was exposed.

Arrays of acoustic sensors are used in various geophysical exploration and antisubmarine warfare applications. Previous sensor

15 arrays commonly used in such applications include a great many active sensors, which are expensive and difficult to operate, primarily because of the large number of wires required to activate the sensors and receive data therefrom. Therefore, there has been considerable interest in using optical fibers as the sensing elements and the telemetry.

20 In the Mach-Zehnder configuration, there are many methods of detecting relative optical phase shifts between the signal and reference fibers. The design of the detection scheme is made nontrivial by the presence of low frequency random temperature and pressure fluctuations which the arms of the interferometer experience. These fluctuations

25 produce differential drifts between the sensing and reference arms of the

interferometer. The drift causes changes in the amplitude of the detected signal (signal fading), and distortion of the signal (frequency up-conversion).

Several detection schemes are currently available: passive homodyne, active homodyne (phase tracking), true heterodyne, and synthetic heterodyne. Each of these techniques has both advantages and disadvantages.

At this time, only the active homodyne has reached a level of high performance (10 to 10^{-6} rad sensitivity range with good linearity and low harmonic distortion), packageabilty (<24 cm^3), and low power consumption. In order to achieve this high level of performance, the technique requires relatively large piezoelectric phase modulators and fast reset circuitry. Large modulators are undesirable in multielement sensors since they increase the active sensor's size and decrease its reliability. Additionally, the need for the sensor circuitry to reset itself every time the environmental noise drives it past its dynamic range adds additional noise. A passive, rather than an active, homodyne system, obviates the two problems discussed above.

According to one aspect of the invention, there is provided a hydrophone demodulator circuit for demodulating an acoustic input signal, comprising:

means for generating a reference signal;

means for modifying an acoustic input signal into a form that can be demodulated;

means for mixing the reference signal with the modified input signal;

means for filtering the mixed signal; and

means for modifying the filtered signal into a demodulated output signal.

According to a second aspect of the invention there is provided a method for demodulating signals indicative of an acoustic input signal, incident upon a hyrophone, comprising the steps of:

generating a reference signal;

modifying an acoustic input signal into a form that can be demodulated;

mixing the reference signal with the modified
5   input signal;

filtering the mixed signal; and

modifying the filtered signal into a demodulated output signal.

Unlike other passive homodyne techniques
10 previously reported, a passive homodyne technique may be designed according to the present invention to provide a very high level of performance with a linear dynamic range of $\sim$100 dB. This large linear dynamic range allows both small and large amplitude signals
15 commonly encountered in applications to be observed with excellent fidelity.

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A crystal oscillator frequency reference and passive filtering be used, which cause low phase noise. One may also include digital phase shifters for mixer references,

which provide low phase noise and stable gain. The signal processing techniques of the circuit are applicable to sensor arrays using a single carrier excitation source, time demultiplexing of individual carrier signals and demodulation of each sensor carrier signal. This demodulator circuit is also applicable to frequency-multiplexed approaches, which utilize direct frequency modulation of the source, slightly unbalanced interferometers, and electronic frequency-division multiplexing.

The demodulation approach avoids signal fading in the interferometer in the time division multiplexed approach by length-modulating the reference fiber at a frequency above the input signal frequency range. Derivations have shown that the baseband input signal can be recovered by processing signals found in the frequency bands around the fundamental and the first harmonic of the reference fiber modulation frequency. In the frequency-multiplexed scheme, signal fading is avoided by frequency modulating the laser directly.

The hydrophone demodulation circuit may provide the reference fiber modulation drive (or corresponding laser frequency-modulation drive) and the interferometer output signal processing.

One embodiment comprises means for producing a reference fiber modulation frequency or reference laser frequency modulation for the means modifying the acoustic input signal, means for measuring the interference pattern of light propagating in two optical fibers, and means for

10 inputting an acoustic wave input to the interference measuring means.

There may be means for removing the harmonic component from first desired reference frequency, means for controlling the output voltage of the means producing a reference fiber or laser frequency modulation frequency, and means for driving the output

15 voltage to the interference measuring means.

It may also comprise a reference arm, a sensing arm, means for outputting a signal containing information in the frequency bands around and between the first desired reference frequency and a second desired reference frequency as the modified

20 input signal, means for buffering the modified input signal upon output from the interference measuring means, and means for connecting the buffered modified input signal to the mixing means.

The circuit may include means for separating the modified input signal into a first and a second channel, a first mixing means for

25 mixing the first desired reference frequency with the modified input signal

in a first channel, and a second mixing means for mixing the second desired reference frequency with the modified input signal in a second channel.

Additionally, there may be means for reducing the carrier
5   ripple in the output of the first mixing means in the first channel, and means for reducing the carrier ripple in the output of the second mixing means in the second channel.

The circuit may also comprise means for differentiating the signal in the first channel, means for differentiating the
10   signal in the second channel, means for multiplying the undifferentiated signal in the second channel by the differentiated signal in the first channel, means for multiplying the undifferentiated signal in the first channel by the differentiated signal in the second channel, means for taking the difference between the first multiplied signal and the second
15   multiplied signal, and means for integrating the difference between the first multiplied signal and the second multiplied signal to form a demodulated output signal.

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In a preferred embodiment of the method, there is produced a frequency signal

(e.g. of approximately 1 MHz), dividing the approximate 1 MHz signal into a first desired frequency, dividing the approximate 1 MHz signal into a second desired frequency that is phase locked to the first

5 frequency, shifting the phase of the first desired frequency, shifting the phase of the second desired frequency, and inputting the first desired frequency into the means modifying the acoustic input signal.

The method may further comprise the steps of providing a reference arm, providing a sensing arm, outputting a signal

10 containing information in the frequency bands around the first desired reference frequency and the second desired reference frequency as the modified input signal, buffering the modified input signal upon output from the interference measuring means, and connecting the buffered modified input signal to the mixing means.

15 The method of the present invention may further include the steps of separating the modified input signal into a first and a second channel, providing a first mixing means for mixing the first desired reference frequency with the modified input signal in a first channel, and providing a second mixing means for mixing a second desired reference frequency

20 with the modified input signal in the second channel.

The present invention may comprise steps of reducing the carrier ripple in the output of the first mixing means in the first channel, and reducing the carrier ripple in the output of the second mixing means in the second channel.

25 The present invention may also include the steps of differentiating the

signal in the first channel, differentiating the signal in the second channel, multiplying the undifferentiated signal in the second channel by the differentiated signal in the first channel, multiplying the

5 undifferentiated signal in the first channel by the differentiated signal in the second channel, taking the difference between the first multiplied signal and the second multiplied signal, and integrating the difference between the first multiplied signal and the

10 second multiplied signal to form a demodulated output signal.

For a better understanding of the invention and to show how the same may be carried into effect, reference will now be made, by way of example, to the

15 accompanying drawings, in which:

Figure 1 schematically illustrates a Mach-Zehnder interferometer;

Figures 2A and 2B graphically illustrate the demodulator input signal with the fundamental signal

20 peaked;

Figures 3A and 3B graphically illustrate the demodulator input signal with the second harmonic peaked;

Figures 4A and 4B graphically illustrate the

25 demodulator input signal with equal amplitudes for the fundamental and second harmonic;

Figure 5 graphically illustrates the peak-detected interferometer signal power spectrum;

Figure 6 schematically illustrates apparatus of

30 the present invention for demodulating an acoustic input wave detected by a hydrophone;

Figure 7 schematically illustrates oscillator and mixer reference circuits that may be included in the apparatus of Figure 6;

35 Figure 8 schematically illustrates a P21 or laser current driver amplifier circuit that may be included in the apparatus of Figure 6;

Figure 9 schematically illustrates mixer circuits that may be included in the apparatus of Figure 6;

Figure 10 schematically illustrates low-pass filter circuits that may be included in the apparatus of Figure 6; and

5   Figure 11 schematically illustrates a sine/cosine demodulator circuit that may be included in the apparatus of Figure 6.

Referring to Figure 1, an apparatus according to this invention may include an

interferometer 20 such as a Mach-Zehnder interferometer. Other
10   interferometers such as a Michelson interferometer (not shown) may also be used with the present invention. The interferometer 20 creates a signal indicative of changes in an acoustic wave incident thereon. In the Mach-Zehnder interferometer 20 a light source 21 provides light to an optical fiber. A portion of the light input to a port 22A of a coupler 22 is coupled
15   from a fiber 24 into a fiber 25 and output from the coupler 22 at port 22D.

The Mach-Zehnder interferometer 20 includes the coupler 22 and a coupler 23 that couple light between the fiber 24 and the fiber 25. The lengths of the fiber 24 and the fiber 25 between the couplers 22 and 23 comprise a reference arm 28 and a sensing arm 30, respectively. The
20   reference arm may be isolated from the parameter being sensed while the sensing arm is exposed to the parameter. In some applications both arms of the interferometer 20 are exposed to the parameter being sensed; and in such applications the interferometer output indicates the difference of the parameter changes on the arms of the interferometer.

25   In general, the reference arms 28 and the sensing arm 30 have

different lengths; however, it is possible to form the interferometer 20 to have equal arm lengths. Light propagating in the reference arm 28 is called the reference signal, and light propagating in the sensing arm 30 is called the sensing signal. The coupler 23 couples a portion of the sensing

5 signal back into the fiber 24 for output at port 23B while also coupling a portion of the reference signal into the sensing fiber 25 for output from the interferometric sensor 20 at port 23D. A portion of the reference signal continues to be guided by the fiber 24 and propagates from port 23A to port 23B. The coupler 23 combines portions of the reference and sensing

10 signals and produces an output signal at port 23B that is a superposition of portions of the reference and sensing signals.

The result of combining the reference and sensing signals is the formation of an interference pattern between the reference and sensing signals at port 23B. This interference pattern is a function of the phase

15 difference ϕ between the reference and sensing signals and is the output of the Mach-Zehnder interferometer 20 that is supplied to a detector 26.

The sensing arm 30 and the reference arm 28 may have quiescent lengths such that the sensing signal and the reference signal combine in phase in the coupler 23. The physical parameter, such as acoustic

20 vibrations, to be measured is coupled to the sensor arm 30 by any convenient means, depending upon the parameter. Changes in the parameter while the reference arm 28 is isolated from changes in the parameter produce an optical path length change ΔL in the sensor arm 30, which causes a phase shift between the reference signal and the sensing

25 signal. The Mach-Zehnder interferometer 20 may be calibrated so that

changes in the sensed parameter may be quantitatively related to the amount of phase shift in the interference pattern.

If the light intensity propagating from port 22B of the coupler 22 toward port 23A of the coupler 23 is I_0, and the coupler 22 has a coupling efficiency of 50%, then the intensity at both port 22B and port 22D will be $\frac{I_0}{2}$. The reference signal undergoes a phase shift θ_T while propagating from the coupler 22 to the coupler 23. While propagating from the coupler 22 to the coupler 23, the sensing signal experiences a phase shift of $\theta_s(t)$, which is a function of the phase shift caused by the fiber 25 and fluctuations in the sensed physical parameter.

The coil 32 in the reference arm 28 may be wrapped around a piezoelectric crystal (PZT) 33. The subsequent expansion and contraction of the piezoelectric crystal 33 produces a phase modulation in light propagating in the reference arm 28. As the pressure front of an acoustic wave contacts the sensing arm 30, it changes the phase of the light propagating in the fiber. Phase changes due to acoustic waves are superimposed on the phase changes due to the phase modulation by the PZT crystal 33, which provides a carrier signal. Other types of phase modulation may be used to provide a carrier signal. The change in phase is then detected by the detecting changes in the interference pattern of the combined optical waves.

The modulation frequency to the phase modulator in the interferometer 20 may be about 10.4 kHz. This selection provides sufficient baseband-to-carrier frequency difference to permit carrier ripple filtering. The modulation frequency is below resonances in the

piezoelectric crystal 33 used to modulate the fiber length.

The detector 26 preferably includes a gated photodiode. The output of the detector 26 is the interferometer output signal. The phase modulation information in the frequency bands centered at 10.4 kHz and

5   20.8 kHz is used to recover the interferometer baseband input signal.

The character of the interferometer output signal is shown in Figures 2, 3 and 4. These figures illustrate the changes that occur in the signal and its spectral content as ambient pressure and temperature vary the relative lengths of the signal and reference arms of the interferometer. A 1 kHz, 50

10   mrad rms sinusoidal input signal was applied to the interferometer.

In Figure 2 the 10.4 kHz fundamental is peaked. The 1 kHz interferometer signal information appears as sidebands around the 20.8 kHz first harmonic. In Figure 3 the situation is reversed, so that the signal sidebands are referenced to 10.4 kHz while the 20.8 kHz harmonic is

15   maximized. Figure 4 shows the signals for a condition intermediate to the other two interference lengths.

The reference fiber modulation drive provided by the demodulation circuit is adjusted to equalize the peak power in the 10.4 kHz and 20.8 kHz carriers. Figure 5 shows the input signal spectrum peak-detected over a

20   long enough time such that all frequencies have peaked during the observation. The first two peaks on the left are the 10.4 kHz and 20.8 kHz carriers used by the demodulator circuit to recover the hydrophone signal.

For phase deviation much less than one radian, the power in each sideband relative to the carrier power can be shown to be

25

$$dBc = 20 \log \phi_{rms} - 3.$$

$$(1)$$

The measurement is made by first peaking the carrier (i.e., 10.4 kHz in Figure 2) and noting its amplitude (-4 dBm). Then the carrier is nulled, the sideband power is measured (-33 dBm in Figure 3) and the difference (29 dB) noted. The phase modulation is calculated from

$$\phi \; rms = 10^{(dBc + 3)/20} \; rad \tag{2}$$

The phase modulation calculated from Figures 2-5 is 50 m rad rms.

External power supplies are necessary to provide ±15V dc @ 0.1 A to operate the demodulation circuit block diagrammed in Figure 6.

The demodulation output voltage signal represents the interferometer signal in the frequency range of 5 to 1280 Hz (at -3 dB). The scale factor is about 1 V/rad.

Figure 6 illustrates a demodulator circuit 45 according to the present invention. A 1 MHz crystal oscillator 52 provides a frequency-stable reference for the circuit. A frequency divider 54 divides the crystal oscillator frequency by 96. The frequency divider 54 thus produces a 10.4 kHz reference fiber modulation frequency. The frequency divider 54 also produces a 10.4 kHz and 20.8 kHz reference signal for input to a pair of mixers 56 and 58.

The initial 10.4 kHz reference fiber modulation frequency is used as an input frequency for the piezoelectric crystal in the interferometer 20. The interferometer 20 serves as the input to the demodulation circuit for an acoustic wave detected by a hydrophone. A bandpass filter 60 removes the 10.4 kHz harmonics from the 10.4 kHz reference fiber modulation signal to yield a sinusoidal waveform. A driver amplifier 62 output may be adjusted by a level control 64 so that proper modulation of the reference

fiber length is obtained.

The interferometer 20 produces output signals that contain information in the bands around 10.4 kHz and 20.8 kHz that can be used to recover the signal fiber baseband input signal. After buffering by a buffer

5　circuit 46, the interferometer output signal is separated into a first and second channel. In the first channel the interferometer output signal is mixed with the 10.4 kHz reference signal by the mixer 56. In the second channel the interferometer output signal is mixed with the 20.8 kHz reference signal by the mixer 58. The output signal from the mixers 56 and

10　58 are low pass filtered through the low pass filter units 65 and 67, respectively. The filtering removes mixer products out of the signal bandwidth of interest.

The outputs of the low pass filter units 65 and 67 are each differentiated by a first and a second differentiator 70 and 72, respectfully.

15　A pair of multiplying circuits 74 and 76 multiply the output of each channel from the differentiator 70 or 72 by the low pass filter output of the other channel. The resulting outputs of the multipliers 74 and 76 are then subtracted from one another by a difference amplifier 78. The outcome of the subtraction is then integrated by an integrator 80 to obtain the final

20　output voltage that represents the length modulation of the signal fiber in the interferometer 20.

Referring to Figure 7, the oscillator and counter circuit provide the 10.4 kHz input to the PZT driver amplifier 62. The 10.4 kHz reference is phase-shifted by a digital phase shifter (shift register) circuit 96, and the

25　phase shifted 10.4 kHz signal is input to the mixer 56. The 20.8 kHz

reference is phase-shifted by a digital phase shifter (shift register) circuit 98 and the phase shifted 20.8 kHz reference signal is input to the mixer 58.

The crystal oscillator 52 provides the 1 MHz frequency which is counted to obtain clock frequencies of 166.6 kHz and 333 kHz. A counter

5   54 is used to further divide the frequency to obtain 20.8 kHz and 10.4 kHz, respectively.

Still referring to Figures 6 and 7, the 10.4 kHz counter output is buffered by a digital buffer 85 and routed to the bandpass filter 60 input in a PZT driver amplifier 62 of Figure 8. The output of the digital buffer 85

10   provides low source impedance so that even order distortion in the 10.4 kHz signal is reduced.

The reference signals for the mixers 56 and 58 must be in phase with the respective 10.4 kHz or 20.8 kHz components of the mixer input signal to obtain maximum mixer gain. The phase shifters 96 and 98

15   provide discretely-adjustable phase shifts that are relatively phase noise free. Phase shifter outputs are available at 1/16 period intervals (22.5 degrees) for the 10.4 kHz mixer reference and the 20.8 kHz reference. Therefore, each mixer reference phase can be set to within 11.25 degrees of an arbitrary phase. Since the mixer relative gain is equal to the cosine

20   of the phase angle between the input signal and the reference, the worst relative gain caused by phase misalignment is cosine 11.25° or 0.231, which is a 1.9% gain loss.

Referring to Figure 8, the bandpass filter 60 is implemented by a low Q, low pass filter which reduces the harmonic content of the 10.4 kHz

25   digital input signal. The driver amplifier 62 provides up to 20 Vpp behind

100 ohms and is short-circuit protected. The output drive circuit includes an operational amplifier 103 and a current driver 105 and associated components that are well known in the art.

5   Referring to Figure 9, the output of the interferometer 20 is input to the buffer 46. This input signal to the buffer 46 contains the 10.4 kHz and 20.8 kHz carriers and their respective sidebands. The input signal amplitude is typically about 2 Vpp. The

10   buffer amplifier 46 provides gain adjustment from 1 V/V to 3 V/V. The input signal has nearly constant amplitude; however, its predominant frequency content shifts from 10.4 kHz to 20.8 kHz and back as interferometer ambient temperature and pressure varies.

15   The amplified input signal is buffered by a non-inverting unity gain amplifier 110 and an inverting unity gain amplifier 112. Two alternate action switches 114A and 114B provide the mixing function. The switches 114A and 114B are connected to the non-

20   inverted and inverted signals so that full-wave mixing (synchronous demodulation) is obtained. The mixer switches 116 are driven by the 10 kHz REF and 20khZ REF obtained from the phase shifters 96 and 98. The mixer gain is $(2/\pi)$ V/V$_p$ in translating the carrier band

25   signals to the baseband.

    The mixers 56 and 58 translate the signals at their respective frequency to dc (the sidebands become baseband signals). Therefore, we will observe a slowly varying voltage in the filtered mixer output that

30   varies with the corresponding carrier level. If the carrier reverses phase, the mixer output voltage reverses polarity.

    The full wave mixer outputs are low-pass filtered (3.6 kHz at 3-dB) and buffered by buffer amplifiers 120

35   and 122 before being fed to the low pass filter sets 65 and 67. This is done to remove the mixer output

products above the signal bandwidth of interest.

Referring to Figure 10, the low-pass filter sets
65 and 67 include a pair of low pass filters 124 and
126 connected to output amplifiers 128 and 130,
5   respectively. The mixer outputs are fed to the low
pass filters 124 and 126. The filters 124 and 126
preferably are constructed using Burr-Brown UAF1
modules. The filters 134 and 136 preferably are
constructed using Burr-Brown UAF11 modules. The
10   filters 124 and 126 have unity gain at dc and provide
approximately 48 dB attenuation at 10 kHz.

The amplifiers 128 and 130 have gain adjustable
from 1 V/V to 2 V/V. These gains are adjusted to
balance the signals in the 20 kHz and 10 kHz channels.
15   The balanced signals are connected to the input of a
pair of carrier ripple filters 142 and 144. The
carrier ripple filters 142 and 144 are identical to the
first set of filters 134 and 136 except that no
amplifiers are used at their outputs. The outputs of
20   the carrier ripple filters 142 and 144 are connected to
the corresponding inputs of a sine/cosine demodulator
150.

Referring to Figure 11, the sine/cosine
demodulator 150 performs the final signal processing
25   necessary to obtain the output signal. The first
amplifiers 152 and 154 in each channel provide offset
correction for as much as positive or negative 1.7V dc
of dc offset in the input signal. The offset
correction amplifiers preferably have gain of 1.1 V/V.
30   The next amplifiers 156 and 158 in each channel
produce an inverting gain of 5 V/V. Differentiators
160 and 162 (γ = 1.62 ms) follow the inverting
amplifiers 156 and 158. The differentiated signal in
each channel is multiplied by the undifferentiated
35   signal in the other channel by either the 10 kHz
channel multiplier 164 or the 20 kHz channel multiplier

166. Subtracting one multiplier 164 or 166 output from the other in the difference amplifier 168 yields the derivative of the interferometer signal.

The final amplifier is an integrator 170 that integrates the output of the difference amplifier 168 for frequencies above about 5Hz. The input to the integrator 170 is preferably ac coupled (3μF x $39K\Omega=$ 0.117 s) to reduce the very-low frequency signals generated by ambient temperature and pressure variations. The low frequency limit (about 5 Hz) for the integrator 170 may be set by a resistor (not shown) and a capacitor (not shown).

A symmetrical fiber optic directional coupler suitable for use in single mode fiber implementations of the invention is described in the March 29, 1230 issue of <u>Electronics Letters</u> Vol. 18, No. 18. pp. 260-261 and in U.S. Patent 4,493,528 issued January 15, 1985 to Shaw et al. That patent is assigned to the Board of Trustees of the Leland Stanford Junior University. The disclosure of that patent is incorporated by reference into the present disclosure. The fiber optic hydrophone structure described herein may be formed using other well-known types of optical couplers.

Other fiber optic couplers such as the tapered biconical coupler may also be used to couple light between optical fibers included in this invention

This invention is described with reference to a specific preferred embodiment. The invention is not limited to the structure or process steps described herein which exemplify the invention rather than limit it.

CLAIMS

1. A hydrophone demodulator circuit for demodulating an acoustic input signal, comprising:

means for generating a reference signal

5 means for modifying an acoustic input signal into a form that can be demodulated;

means for mixing the reference signal with the modified input signal;

means for filtering the mixed signal; and

10 means for modifying the filtered signal into a demodulated output signal.

2. The hydrophone demodulator of claim 1, wherein the reference signal generating means comprises:

means for producing a frequency signal of

15 approximately 1 MHz;

means for dividing the approximate 1 MHz signal into a first frequency;

means for dividing the approximate 1 MHz signal into a second frequency;

20 means for shifting the phase of the first frequency;

means for shifting the phase of the second frequency; and

means for inputting the first frequency into the

25 means for modifying the acoustic input signal.

3. The hydrophone demodulator of claim 1 or 2, wherein the means for modifying the acoustic input signal comprises:

means for producing a reference fiber modulation

30 frequency for the means modifying the acoustic input signal; means for measuring the interference pattern of light propagating in two optical fibers; and

means for inputting an acoustic wave input to the interference measuring means.

35 4. The hydrophone demodulator circuit of claims 2 and 3 wherein the acoustic input signal modifying means

comprises;

means for removing the harmonic component from the first reference frequency;

means for controlling the output voltage of the

5 means producing a reference fiber modulation frequency; and

means for driving the output voltage to the interference measuring means.

5. The hydrophone demodulator circuit of claim 3

10 or 4 when appended to claim 2 wherein the interference measuring means comprises:

a reference arm;

a sensing arm;

means for outputting a signal containing

15 information in the frequency bands around and between the first reference frequency and the second reference frequency as the modified input signal;

means for buffering the modified input signal upon output from the interference measuring means; and

20 means for connecting the buffered modified input signal to the mixing means.

6. The hydrophone demodulator of any one of the preceding claims, wherein the mixing means comprises: means for separating the modified input signal into a

25 first and a second channel;

a first mixing means for mixing a first reference frequency with the modified input signal in a first channel; and

a second mixing means for mixing a second

30 reference frequency with the modified input signal in a second channel.

7. The hydrophone demodulator of claim 6, wherein the filtering means comprises:

means for reducing the carrier ripple in the

35 output of the first mixing means in the first channel; and

means for reducing the carrier ripple in the output of the second mixing means in the second channel.

8. The hydrophone demodulator of claim 6 or 7, wherein the filtered signal modifying means comprises:

means for differentiating the signal in the first channel;

means for differentiating the signal in the second channel;

means for multiplying the undifferentiated signal in the second channel by the differentiated signal in the first channel;

means for multiplying the undifferentiated signal in the first channel by the differentiated signal in the second channel;

means for taking the difference between the first multiplied signal and the second multiplied signal; and

means for integrating the difference between the first multiplied signal and the second multiplied signal to form a demodulated output.

9. A method for demodulating signals indicative of an acoustic input signal, incident upon a hydrophone, comprising the steps of:

generating a reference signal

modifying an acoustic input signal into a form that can be demodulated;

mixing the reference signal with the modified input signal;

filtering the mixed signal; and

modifying the filtered signal into a demodulated output signal.

10. The method of claim 9, wherein the step of generating a reference signal comprises the steps of:

producing a frequency signal of approximately 1 MHz;

dividing the approximate 1 MHZ signal into a first

frequency;

dividing the approximate 1 MHz signal into a
second frequency;

shifting the phase of the first frequency;

5   shifting the phase of the second frequency; and

inputting the first frequency into the means
modifying the acoustic input signal.

11. The method of claim 9 and 10, wherein the
step of modifying the acoustic input signal comprises

10   the steps of:

producing a reference fiber modulation frequency
for the means modifying the acoustic input signal;

measuring the interference pattern of light
propagating in two optical fibers; and

15   inputting an acoustic wave input to the
interference measuring means.

12. The method of claim 10 and 11 wherein the
step of acoustic input signal modifying comprises the
steps of:

20   removing the harmonic component from the first
reference frequency;

controlling the output voltage of the means
producing a reference fiber modulation frequency; and

driving the output voltage to the interference

25   measuring means.

13. The method of claim 11 or 12 when appended to
claim 10, comprising the steps of:

providing a reference arm;

providing a sensing arm;

30   outputting a signal containing information in the
frequency bands around and between the first reference
frequency and the second reference frequency as the
modified input signal;

buffering the modified input signal upon output

35   from the interference measuring means; and

connecting the buffered modified input signal to

the mixing means.

14. The method according to any one of claims 10 to 13, wherein the step of mixing the reference signal with the modified input signal further comprises the steps of:

separating the modified input signal into a first and a second channel;

providing a first mixing means for mixing the first reference frequency with the modified input signal in a first channel; and

providing a second mixing means for mixing the second reference frequency with the modified input signal in a second channel.

15. The method of claim 14, wherein the step of filtering the mixed signal comprises the steps of:

reducing the carrier ripple in the output of the first mixing means in the first channel; and

reducing the carrier ripple in the output of the second mixing means in the second channel.

16. The method of claim 14 or 15, wherein the step of modifying the filtered signal comprises the steps of:

differentiating the signal in the first channel;

differentiating the signal in the second channel;

multiplying the undifferentiated signal in the second channel by the differentiated signal in the first channel;

multiplying the undifferentiated signal in the first channel by the differentiated signal in the second channel;

taking the difference between the first multiplied signal and the second multiplied signal; and

integrating the difference between the first multiplied signal and the second multiplied signal to form a demodulated output signal.

17. A demodulator substantially as hereinbefore

described with reference to Figures 6, or that figure as modified by Fig 7, 8, 9, 10 and/or 11 of the accompanying drawings.

18. A method of demodulating substantially as
5   hereinbefore described with reference to Figs. 6, or that figure as modified by Figures 7, 8, 9, 10 and/or 11 of the accompanying drawings.

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